Drizzle and Entrainment in Coastal Marine Stratocumulus Clouds

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LONG-TERM GOAL

The long term-goal of this project is to provide an improved description and understanding of the effects of drizzle and entrainment on coastal marine boundary layer clouds that will provide a basis for developing, improving, and evaluating cloud and boundary layer representations in LES, mesoscale and large-scale forecast models.

OBJECTIVES

- Characterize vertical distribution of drizzle and how it relates to cloud circulations
- Investigate the relative role of cloud thickness and cloud turbulence levels on drizzle production
- Explore the mesoscale and convective-scale variability of drizzle
- Study the relationship of coherent eddies in the boundary layer to entrainment
- Document the structure and characteristics of entrainment circulations for a wide-range of stability and shear conditions
- Define the evolution of turbulence and coherent boundary layer structures during the formation and dissipation of coastal stratus

APPROACH

Observations from a suite of surface-based remote sensing systems were used to resolve the fine-scale microphysical and turbulence structure in marine coastal stratocumulus clouds. The centerpiece for the surface-based remote sensing is a short wavelength (3 mm) Doppler radar. Spectral processing of Doppler signals from this radar is being used for cloud microphysical and turbulence retrievals. Liquid water path was observed continuously from the site using a microwave radiometer operated by Roger Marchand from Penn State University. Continuous observations of boundary layer height and winds were obtained from the Naval Postgraduate School (NPS) 915 MHz wind profiler. The Twin Otter research aircraft operated by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) provided *in situ* observations for evaluating and improving the remote sensing retrievals and providing details of drizzle and entrainment processes.

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WORK COMPLETED

Initial work on this project involved the development of hardware and analysis techniques for the June-July 1999 field deployment to Monterey. During this deployment the remote sensing systems were operated from a site on the shore of Monterey Bay near Marina California. From 14 June to 9 July 1999 more than 100 hours of high-quality cloud observations were made with the 94 GHz radar. Doppler spectra were obtained at 3-second intervals and a vertical resolution of 30 m. Supporting observations were made continually with the microwave radiometer, two ceilometers, upward looking shortwave and longwave radiometers, and standard meteorological instruments. We launched rawindsondes from the site to define boundary layer structure and the Naval Postgraduate School 915 MHz wind profiler provided continuous observations of low-level winds and boundary layer depth at a site a few miles inland from the other measurements. A total of 20 flights were made with the CIRPAS Twin Otter in support of this and several other related projects. Although flight restrictions limited extensive aircraft observations directly in the clouds sampled by the radar, the location of the site allowed the aircraft to fly over the site during takeoffs and missed approaches. Observations were also made upstream from the site on several Twin Otter flights. Processing of the data from all of the observing systems is in progress. Reports describing operations, instruments and synoptic conditions and results from initial analyses are available at the Drizzle and Entrainment Cloud Studies (DECS) Internet site.

RESULTS

Excellent cloud conditions were observed during DECS. Cloud top ranged from about 400-600 m with cloud base extending from near the surface to 200m. Heavy drizzle, mainly occurring in the early morning hours, was often observed in clouds that were less than 400 m thick. Heavy drizzle was often observed in the early morning at the site. The transition to non-drizzling clouds and then to the break-up later in the day was observed on several days. Examples of the radar returns for a non-precipitating cloud and one with light drizzle are shown in Figure 1. These samples illustrate the utility of the radar for defining vertically coherent structures in the clouds using the first three moments of the Doppler spectra from the radar. Updraft and downdraft structures are clearly discernible for the non-precipitating case. In the drizzle case, larger-scale circulations (indicated by the red areas in the reflectivity and the blue areas in the velocity plots) are associated with the drizzle observed in the lower part of the cloud. We are currently investigating possible connections between the regions of narrow spectral width (low turbulence and/or narrow drop-size distributions) that originate at cloud top and in some cases penetrate through the entire depth of the cloud layer.

The high temporal resolution (3-second) Doppler spectra, obtained for the entire 100 hours of cloud observations, provide quantitative signatures of drizzle and turbulence in the clouds. Thus these spectra can be used to describe the time evolution of the turbulence and microphysics without the limitations of using retrievals based on the statistical moments of the raw Doppler radar data (Fritsch, 1995a,b; Kollias and Albrecht, 1999).

a)

b)

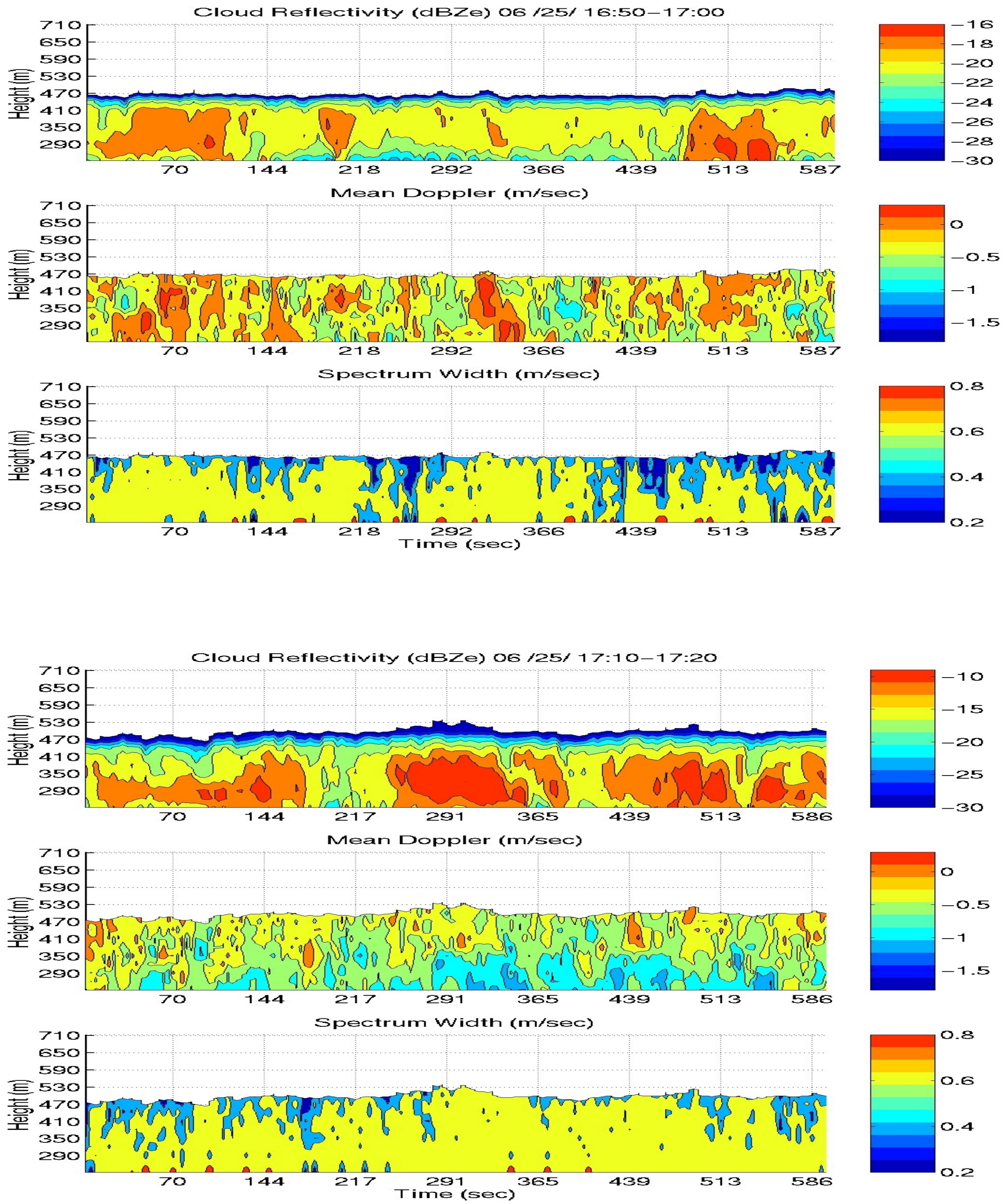

Figure 1. Example of reflectivity, vertical velocities, and spectrum width for 10 minutes of observations made on 25 June 1999 of a coastal stratus cloud where a) little or no drizzle was observed, and b) light drizzle is observed.

IMPACT/APPLICATION

The cloud and boundary layer observations made during the field phase of this project represent a unique data set for studying the dynamics and microphysics of coastal stratus clouds. Doppler spectra obtained from the cloud radar represent the most extensive and detailed observations of this type in marine coastal stratus. With proper analysis these should substantially advance our understanding of drizzle and entrainment processes.

TRANSITIONS

The techniques developed to retrieve cloud microphysics and turbulence from the radar observations provide a basis for similar retrieval techniques for use with a 94 GHz radar that is currently being developed under an ONR initiative. The cloud and boundary layer observations made during the field phase of DECS will be available for comparison with the boundary layer and cloud structure from NRL COAMPS simulations made for the area of interest.

RELATED PROJECTS

Several scientists were involved in related projects during the Monterey coastal cloud experiment. Qing Wang from the Naval Postgraduate School was heavily involved with the CIRPAS Twin Otter in support of a NSF study of the interaction between coastal flows and marine stratocumulus. Dean Hegg of University of Washington and Rick Flagan of CalTech were involved in aerosol studies using the CIRPAS aircraft during DECS. Graeme Stephens headed a NASA/DOE project in support of CloudSat, a NASA project to use a 94 GHz radar in space. In support of this project, an airborne cloud radar was operated by the University of Mass on a DOE Twin Otter during DECS. This aircraft flew coordinated patterns over the CIRPAS Twin Otter aircraft as it sampled clouds within the view of the radar overhead. The airborne radar was also flown over the surfaced-based radar on several occasions for detailed intercomparisons. Roger Marchand of Penn State operated a microwave radiometer and surface shortwave and longwave radiometers at the radar site during DECS. He headed efforts to make overflights over the site with the NASA ER-2 in support of EOS validations. Flights made with the CIRPAS Twin Otter during this experiment were also use in support of a NSF sponsored program to study holes and rifts in stratus observed off of the coast. Halflidi Jonsson and Phil Durkee of NPG and myself were involved in this NSF project.

REFERENCES

Kollias, P and B. Albrecht, 1999: The turbulence structure of a continental stratus clouds from 94 GHz Doppler radar observations. *J. Atmos. Sci.* (In press)

Frisch, A.S., C.W. Fairall and J.B. Snider, 1995a: Measurements of stratus cloud and drizzle parameters in ASTEX with a K_α-band Doppler radar and microwave radiometer. *J. Atmos. Sci.*, **52**, 2788-2799.

Frisch, A.S., C.W. Fairall, W.H. Schubert and J.S. Gibson, 1995b: Doppler radar measurements of turbulence in marine stratiform cloud during ASTEX. *J. Atmos. Sci.*, **52**, 2800-2808.

PUBLICATIONS

A description of the instrumentation, operations and synoptic conditions during DECS and preliminary data analyses may be found at the Internet site http://orca.rsmas.miami.edu/monterey/.